International Journal of Electrical and Electronics Engineering Research (IJEEER)
ISSN (P): 2250–155X; ISSN (E): 2278–943X
Vol. 12, Issue 1, Jun 2022, 1–14

ERROR TRACKING TECHNIQUE FOR SYSTEM STABILITY IN LTE NETWORK USING MIXED SENSITIVITY TECHNIQUE

PHILIP-KPAE F.O. [1], NWABUEZE C. A. [2], MBACHU C. B. [3] & AGBARAJI E.C. [4]

[1] *Department of Electrical/Electronic Engineering, School of Engineering, Kenule Beesor Saro-iwa Polytechnic Bori, Rivers State, Nigeria*

[2, 3] *Department of Electrical/Electronic Engineering Faculty of Engineering, Chukwu Emeka Odumegwu Ojukwu University, Anambra State, Nigeria*

[4] *Department of Computer Engineering, School of Engineering Technology, Federal Polytechnic Nekede, Owerri, Imo State, Nigeria*

ABSTRACT

Transmission Control Protocol (TCP) degrades the performance of LTE wireless networks when overwhelmed by an increase in the number of connections in the network. There is a need to develop a robust compensator that will improve the overall performance of TCP based 4G-LTE wireless network. Mixed Sensitivity Optimization Synthesis (Mixsyn) is a weighting function dependent controller with a robust compensator that can be used to improve a TCP base LTE network. The TCP performance indicator that are looked at include reduction in tracking error and overall stability of the system. The system with the Mixsyn achieved a better tracking error of 1.14dB and 1.07dB and high sensitivity to disturbance of 0.0059dB and 0.0116dB. With this result, the Mixsyn technique was used to improve the TCP based LTE network as can be seen in the analysis from the result to improve the performance and stability of the system sensitivity to disturbance and system output error. The Mixsyn achieved a 99.57% and 99.575% of 0.1 seconds time base value of the system. It was concluded, that the Mixsyn TCP network achieved an improved performance and robust stability of the system even in the presence of high disturbances.

KEYWORDS: TCP, LTE, Mixsyn, Settling Time, Sensitivity to Disturbance.

Received: Jan 11, 2022; **Accepted**: Jan 31, 2022; **Published**: Feb 18, 2022; **Paper Id.**: IJEEERJUN20221

1.0 INTRODUCTION

The continuous technological growth in information communication technology especially in telecommunication industries and the increasing demand for higher speed data transfer for different personal and business transactions has brought about the generations of wireless broadband development. Due to the tremendous growth of data usage in business, individual and government transactions on the mobile networks, there has been the problem of disturbances in the wireless networks in the form of data congestion, noise leading to degradation of network performance. In other to solve these problems, there have been continuous research works going on to proffer solutions to the wireless networks traffic congestion. The Long Term Evolution (LTE) is the 3rd Generation Partnership Project (3GPP), all-IP wireless protocol that evolved from Global System for Mobile Communications (GSM) [2]. LTE brought about high speed data transfer rate but has equally suffered from various disturbances due to its interaction with the transport control protocol (TCP). The 4G network concentrated on data services that support only the Packet Switched (PS) domain; Packet-switched networks use buffers to accommodate transient

traffic bursts. The functionality of these buffers prevents packet loss and maintains high output link utilization. Packet loss may happen in the buffer of a node, if the size of the buffer becomes less than the flow of packets into the buffer, for overcoming the loss of packets in the buffer, it can be reduced by setting the threshold limit and if it is reached then the rate of flow of packets should be reduced [1]. The threshold set for the buffer is called the buffer size [3].

In order to address the problem of congestion control in TCP, the Proportional Integral Derivative (PID) in [13] is used but the high overshoot in the results does not ensure the desired enhancement of the performance of the system. This problem of PID results from the limitation in its turning technique and selection of the controller gains. This problem of limitation in tuning capability is addressed using mixed sensitivity synthesis (mixsyn). This method applies weighting functions, which can be tuned without limitations on the TCP queue transfer function to improve the performance characteristics of the TCP queue over LTE network through loop shaping. The mixed sensitivity synthesis finds a controller that can improve the system and satisfy the desired system characteristics. In this work, the mixed sensitivity synthesis is proposed. LTE network requires a reliable data transfer protocol such as TCP. Since the TCP is a reliable data transfer protocol with speed and error rate as the major drawback factors, this work focuses on improving the TCP based LTE network speed and error rate.

This paper is aimed at enhancing the performance of TCP for LTE networks using mixed sensitivity synthesis. By proposing the adoption of the mixed sensitivity synthesis. Mixed-sensitivity synthesis loop shaping enables the design of a H-Infinity controller by simultaneously shaping the frequency responses for tracking and disturbance rejection, noise reduction and robustness, and controller effort. This technique is a useful way to balance the necessary tradeoff between performance and robustness. To use this technique, the desired responses are converted into up to three weighting functions that the mixsyn command uses to synthesize the controller [6].

2.0 REVIEW OF RELATED WORKS

[5] Carried out research work on the efficiency of a PID-based Congestion Control for High-speed IP networks. They stated that network congestion occurs when a receiving node is receiving more data than it can handle or forward to an output interface. It leads to significant performance degradation: additional delays and massive packet losses. Congestion control algorithms are aimed to solve such stated problems. In their opinion, this is an automatic control of a sender's parameters, which describe the performance of the data send process, adaptability for different connection cases and the ability to share link resources fairly with other connections.

The aim of their research was to investigate PID-based congestion control in terms of Cloud BDT and Bit Booster projects. According to them, the idea behind the usage of PID (Proportional – Integral – Derivative) control in congestion control algorithm lies in the fact that this type of control can be very flexible, scalable and adaptive. It can be easily extended by additional modules like tune loop or artificial neural network. They opined that the main challenges for modern congestion control are high bottleneck bandwidth utilization, low bottleneck queue delays, automatic scalability to different channel conditions (different bandwidth and different delays) [14], adaptation for sudden changes over connection like rerouting, applicability in wireless networks and resource sharing etc.

[5] presented that a PID controller is a widely used control loop feedback mechanism; it continuously calculates an error value as a difference between a desired level of a controlled value Set point, (SP) and a measured process value (PV).

Some limitations in their work are;

- The TCP/AQM system dynamic model was not considered in the design of the PID congestion controller. Hence there is no clear relationship between the controller and the plant, which should help to realize a more stable and robust system.
- The stability of the TCP queue was not considered for analysis which is not good for such a physical system with various forms and sources of disturbances.
- The transient state and steady state trajectories of the TCP queue suffered from significant oscillations and this shows that the system is not robustly stable. This limitation could be the cause of the significant difference in the results with variations in the RTT.

[8] Carried out research on the Design of feedback controllers for TCP/AQM networks. They proposed a novel proportional-differential-type feedback controller called Novel-PD as a new active queue management (AQM) to regulate the queue length with small oscillation. This measures the current queue length and uses the current queue length and differential error signals to adjust packet drop probability dynamically. In their work, they considered control theorems in the analysis of TCP/AQM system stability and designed the TCP control by selecting control gain parameters of Novel-PD in order to achieve a system with improved stability. The PD controller was compared with random early detection (RED), random exponential marking (REM), proportional integrator (PI) and proportional derivative (PD) controller. The result showed that the PD was stable and achieved faster response in dynamic environments where number of TCP connections, bottleneck capacity, round trip time (RTT) keeps changing. The proposed PD controller according to [8] outperforms other AQM schemes.

Their work shows that the REM, RED and PI controller designed methods recorded very high level of oscillations, especially at the steady state trajectories of the TCP/AQM controlled networks. These results showed the worst performance and unstable TCP/AQM systems. Secondly, in order to surely ascertain robust stability, the analysis of a system designed must be carried out in frequency domain which provides the means to measure the stability margins. However, the analysis of the system design in this work was carried out in time domain which does not provide the means to measure the stability margin. Therefore, the design in this work lacks characteristics to ensure the best performance and stability of the PD based controller for TCP/AQM network.

[15] in their research work titled “Active Queue Management in TCP Networks Based on fuzzy-PID Controller” introduced a novel and robust active queue management (AQM) scheme based on a fuzzy controller, called hybrid fuzzy-PID controller. They stated that in the TCP network, AQM is important to regulate the queue length by passing or dropping the packets at the intermediate routers. RED, PI, and PID algorithms have been used for the design of TCP/AQM systems. But they argued that those algorithms show weaknesses in the detection and control of congestion under dynamically changing network situations. In order to improve the system, a novel Fuzzy-based proportional-integral derivative (PID) controller, which acts as an active queue manager (AQM) for Internet routers, was proposed. These controllers are used to reduce packet loss and improve network utilization in TCP networks. Some limitations in there are ;

- However, the results in their work showed that the speed of the actual output signal or the actual queue length trajectory is greater than unity and therefore did not attain the speed required for TCP/AQM system over LTE network.

- The sensitivity measured in their work was not analyzed in frequency domain rather it was analyzed in time domain; therefore it is difficult to ascertain the real sensitivity behaviors of the various methods of the AQM design applied in their work.

It is important to note that in most research works, the analysis of the congestion controller design did not consider the speed of the TCP queue over LTE network which can only be well analyzed in frequency domain in order to ascertain the network real performance using the base time value as a standard.

3.0 METHODOLOGY

This data collection data area enables the study of the behavior of TCP over LTE network in a high data traffic area. This will help to understand the causes of regular call drops, call hanging or poor call connections that occur in most places.

If the TCP measured time is high, which means that the speed of the TCP over LTE network is low, then the spectrum utilization will be low and such will cause poor performance of the network. It will also increase the error rate which affects the accuracy and reliability of the network. Thus the lower the time of packet delivery, the better the network speed.

In this work, TCP based LTE network was considered and the focus here is to improve the performance of the TCP in terms of the following characteristics:

- Data traffic congestion control speed which is normally reflected in the time domain graph of the transfer function of the TCP/AQM model.
- The data transfer error which is reflected in the frequency domain graph of the transfer function model of the TCP/AQM as the reference tracking error.
- The cross-over frequency ω_c; The cross-over frequency is proportionally inverse to the response time of the system, so it means that to get a faster system, $\omega_c$must be as high as possible [5].

Taking into consideration the following existing dynamics of the TCP queue system:

$$\begin{cases} G_W(s) = \dfrac{\frac{R_0 C^2}{2N}}{\left(s+\frac{2N}{R_0^2 C}\right)} \\ G_q(s) = \dfrac{\frac{N}{R_0}}{\left(s+\frac{1}{R_0}\right)} \end{cases} \tag{1}$$

where $G_W(s)$represents the TCP's dynamic model without time delay and $G_q(s)$represents the queue dynamic model.

These dynamic models can be demonstrated diagrammatically as shown in Figure 1.

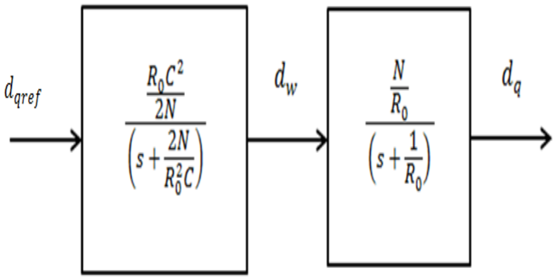

Figure 1: TCP queue model without time delay

The transfer function of the TCP queue without time delay becomes:

$$\frac{d_q}{d_{qref}} = G_W(s).G_q(s) \tag{2}$$

$$\frac{d_q}{d_{qref}} = \frac{\frac{R_0C^2}{2N}}{\left(s+\frac{2N}{R_0^2C}\right)} \cdot \frac{\frac{N}{R_0}}{\left(s+\frac{1}{R_0}\right)} \tag{3}$$

The AQM action can be seen as a compensator that works together with the TCP dynamic in order to improve the performance of the system. Considering the AQM time delay as shown in Figure 2 which is one of the essential practical features of the network dynamics that must be captured in the model during the design stage of the network performance optimization, the TCP queue model becomes:

$$\begin{cases} G_W(s) = \frac{\frac{R_0C^2}{2N}}{\left(s+\frac{2N}{R_0^2C}\right)} e^{-sR_0} \\ G_q(s) = \frac{\frac{N}{R_0}}{\left(s+\frac{1}{R_0}\right)} \end{cases} \tag{4}$$

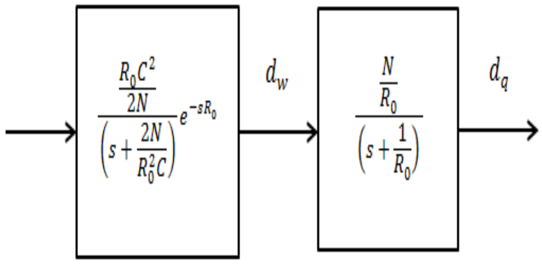

Figure 2: TCP Queue Model with Time Delay

The transfer function becomes:

$$\frac{d_q}{d_{qref}} = \frac{\frac{R_0C^2}{2N}}{\left(s+\frac{2N}{R_0^2C}\right)} e^{-sR_0} \cdot \frac{\frac{N}{R_0}}{\left(s+\frac{1}{R_0}\right)} \tag{5}$$

Solving the differential equation for the function *Gp*(*s*) is the plant transfer function and takes into consideration

the queue dynamics ($Gq(s)$) and the TCP behavior dynamics ($Ptcp(s)$), the following equation was obtained:

$$G_p(s) = \frac{\left(\frac{C^2}{2N}\right)e^{-sR_0}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)} \tag{6}$$

The TCP/AQM dynamic model transfer function can be demonstrated diagrammatically as shown in Figure 3.

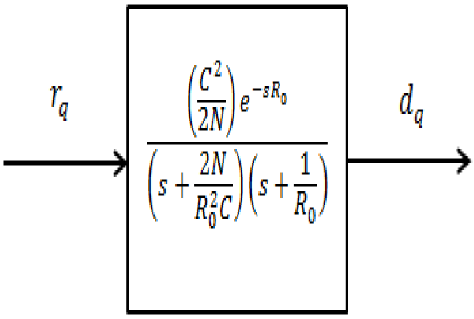

Figure 3: The TCP/AQM Model Plant.

Where r_q is the input signal into the TCP/AQM system

3.1 Performance Analysis in Time Domain.

TCP model performance analysis was based on the determination of the following characteristics: Steady state error and settling time of the system output in the Time Domain.

Steady State Error: The value of the steady state error determines the level of error existing in the data transfer in the LTE network. This relates to the amount of data loss and other forms of disturbances existing in the network. The steady state error is deduced from the time domain graph of the TCP/AQM model queue length output trajectory. Steady-State Error is the difference between the input and output of a system after the natural response has decayed to zero [9]' [10]. This means that minimizing the steady state error value will help to improve the performance of the TCP/AQM system [14].

Settling Time: The settling time is the time required for the system output to settle within a certain percentage of the input amplitude. This means that the settling time determines the speed of the network during the data transfer and congestion control of the system [14].

3.2 Performance Analysis in Frequency Domain

The performance analysis in frequency domain examines the behavior of the system output response in frequency against magnitude in decibel (dB). The frequency domain analysis reveals the hidden or real internal behavior of the system. When a system satisfies the desired frequency analysis characteristics, it is said to be well designed. This is because a system may seem to achieve good performance in time domain but achieves poor performance in frequency domain analysis. Thus, a good system design must include the frequency analysis in other to examine the real behavior of the system.

In this work, the system tracking error is analyzed in frequency domain. The tracking error is the difference

between the actual output and the desired output of the system. It can be explained more as the ability of the system actual output to track the desired output characteristics. The target of most design works is to achieve a 0dB error which shows that the system actual output has no difference with the desired output characteristics.

3.3 TCP Over LTE Network Model

In order to achieve the TCP model performance improvement, a feedback method of control was employed. The feedback system is roughly made of two parts: the plant that describes the system dynamics, and a controller, which must ensure that the system performs robustly with good time-response to the inputs [5]. The feedback system provides the means to minimize the system error, and improve the time response of the system. In this feedback mechanism, the TCP output is measured and compared with the reference input into the system to produce an error, shown in Figure 4. This error requires a controller and the output of the controller u as demonstrated in Figure 5 is fed into the TCP/AQM plant in order to produce an improved output signal.

The error, being a dynamic signal, changes with time as a result of the instantaneous changes in the input signal and the disturbances existing in the system. As a result, the compensation or control of the error is always a difficult task in most control systems.

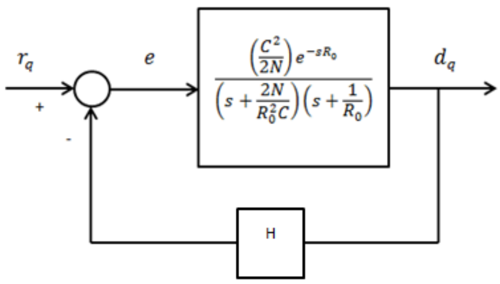

Figure 4: Feedback Mechanism for the Plant

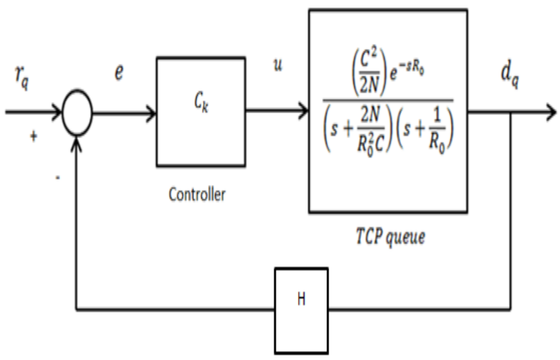

Figure 5: Feedback Mechanism with A Compensator for the Plant

$$\frac{C^2}{2N} = x \tag{7}$$

$$\frac{2N}{R_0^2 C} = n \tag{8}$$

$$\frac{1}{R_0} = m \tag{9}$$

Where H=1

Substituting the Equations 7, 8 and 9 into equation 6, the TCP transfer function can be represented as follows:

$$G = \frac{xe^{-sR_0}}{(s+n)(s+m)} \tag{10}$$

For the closed loop model, the transfer function of the feedback system is given as follows:

$$\frac{d_q}{r_d} = \frac{GC_k}{1+GC_k} \tag{11}$$

Substituting the Equations 10 into Equation 11 gives the following:

$$\frac{\frac{C_k xe^{-sR_0}}{(s+n)(s+m)}}{1+\frac{C_k xe^{-sR_0}}{(s+n)(s+m)}} \tag{12}$$

$$\frac{\frac{C_k xe^{-sR_0}}{(s+n)(s+m)}}{\frac{(s+n)(s+m)+C_k xe^{-sR_0}}{(s+n)(s+m)}} \tag{13}$$

$$\frac{C_k xe^{-sR_0}}{(s+n)(s+m)} \times \frac{(s+n)(s+m)}{(s+n)(s+m)+C_k xe^{-sR_0}} \tag{14}$$

$$\partial(s) = \frac{C_k xe^{-sR_0}}{(s+n)(s+m)+C_k xe^{-sR_0}} \tag{15}$$

Where $\partial(s)$ is the modified TCP based LTE system transfer function.

Substituting the equations for 7, 8 and 9 into Equation 4.2, gives:

$$\partial(s) = \frac{C_k \cdot \frac{C^2}{2N} \cdot e^{-sR_0}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)+C_k \cdot \frac{C^2}{2N} \cdot e^{-sR_0}} \tag{16}$$

$$\partial(s) = \frac{\frac{C^2 C_k e^{-sR_0}}{2N}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)+\frac{C^2 C_k e^{-sR_0}}{2N}} \tag{17}$$

3.4 TCP Performance Improvement Using Mixed Sensitivity Synthesis

The mixed-synthesis involves the use of weighting factors W1 and W2 on the TCP queue plant to achieve the desired system performance. It forms the augmented function using the weighting functions and the TCP queue plant. The methods find the value of the controller C_k that can improve the performance of the system through loop shaping which involves the tuning of the weighting functions.

The mixed synthesis controller design method uses the MATLAB syntax "aug" to connect the weighting functions with the TCP queue transfer function to form the augmented function. It uses the MATLAB syntax "mixsyn" or "hinfsyn" to find the controller C_k which satisfies the desired performance through loop shaping. The TCP performance improvement involves the reduction of the settling time and the tracking error. These characteristics determine how fast and accurate the TCP queue over LTE network performs. Figure 6 shows the controlled system with weighting functions

W1 and W2. Figure 7 show the controlled system with the augmented function.

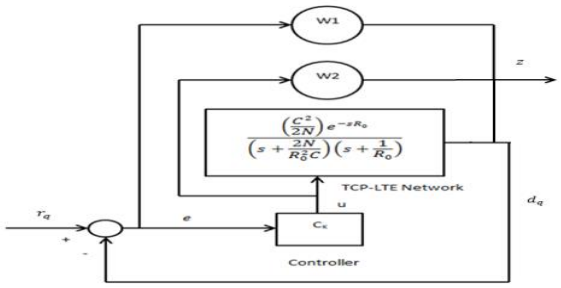

Figure 6: Controlled System with Weighting Functions W1 and W2

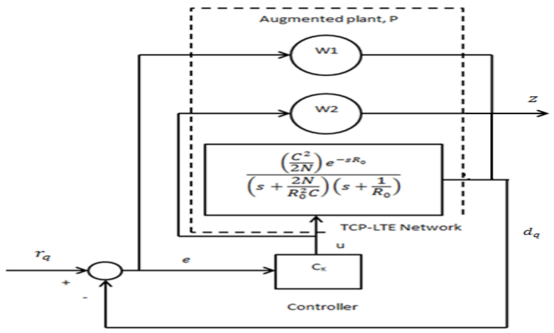

Figure 7: Controlled System with the Augmented Factor

The augmented factor is made up of the weighting factors and the TCP queue plant. This is formed using the MATLAB syntax:

>>aug(G, W1, W2)

The mix-synthesis algorithm is presented as follows:

- Apply TCP queue transfer function,

$$G_p(s) = \frac{\left(\frac{C^2}{2N}\right)e^{-sR_0}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)} \quad (18)$$

- Formulate the improved system function

$$\partial(s) = \frac{\frac{C^2 C_k e^{-sR_0}}{2N}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)+\frac{C^2 C_k e^{-sR_0}}{2N}} \quad (19)$$

- Find the controller C_k using mixed-synthesis design method through MATLAB simulation that can improve the output of the system and satisfy the desired characteristics.
- Apply the weighting functions W1(s) and W2(s) on the TCP queue transfer function $G_p(s)$
- Form the augmented function P(s) with Gp(s), W1(s) and W2(s) using MATLAB operator, aug:

$$P(s) = aug(Gp, W1, W2) \tag{20}$$

- Generate the controller C_k in state space using the mixsyn syntax in MATLAB:

$$[C_k] = mixsyn(P) \tag{21}$$

- Compute the open loop gain function:

$$L = C_k \times P \tag{22}$$

- Compute the sensitivity function:

$$S = (1 + L)^{-1} \tag{23}$$

- Plot a time graph for the improved system function $\partial(s)$ to determine the settling time, overshoot and steady state error.
- Plot a frequency graph for the improved system function $\partial(s)$ to determine the tracking error.

The algorithm for the controller design using mixed-synthesis technique is implemented in MATLAB m-file for the TCP queue performance improvement and analysis.

Table 1.: Simulation Parameters for the LTE Network [2] [4].

Parameter	Value
Link Capacity, C	3750 or 4200 packets/s
Round Trip Time, R	0.25s
Bandwidth of Server link	100Mbps
Load Factor, N	60
Packet Size	1500 Bytes
Window Size	48 Kbytes
Simulation Time	30 sec

Substituting the parameters of the TCP based LTE network in table into the system transfer function G:

For link capacity C=3750 packet/seconds

$$G = \frac{25310000000}{s^2 + 4.002s + 0.008} \tag{24}$$

For link capacity C=4200 packet/seconds

$$G = \frac{31750000000}{s^2 + 4.002s + 0.007143} \tag{25}$$

4.0 RESULTS AND ANALYSIS

The modified LTE network using mixed sensitivity synthesis shows the improved TCP based LTE network performance based on the damping time of the modified LTE system output response. The compensator that can help to improve the LTE network was developed by modifying the weighting functions.

Experiment I

This was carried out in three scenarios: when the link capacity is 3750 packets/seconds and 4200 packets/seconds using the weighting functions as expressed as follows:

$$W1 = \frac{1000(0.001s+10)}{s+10} \tag{26}$$

$$W2 = tf\left(\frac{1}{0.1}\right) \tag{27}$$

First Scenario of First Experiment I - When C=3750 Packet/Seconds

The first scenario of experiment I was carried out using TCP based LTE network with link capacity =3750 packet/seconds:

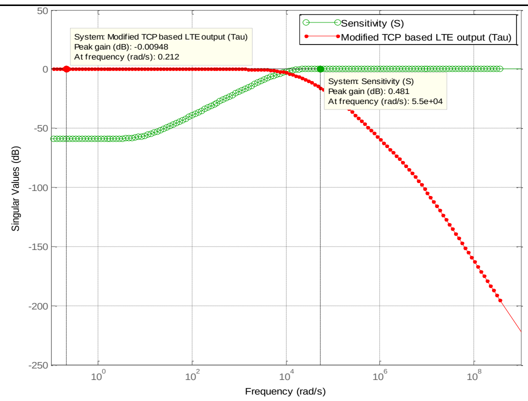

Figure 8: Singular Value Plot of the LTE Network When C=3750 Packets/Seconds

The results in Figure 8 shows that:

The modified TCP based LTE network model output recorded an error of 0.00948. This means that the modified system achieved an improvement in the network actual output responds with reduced error. The modified system recorded a sensitivity peak of 0.481dB. This means that the system can reject disturbances very well with reduced sensitivity.

The developed compensator Ck using mixed sensitivity synthesis for the first experiment with a link capacity of 3750 packets/seconds and weighting functions in equations 26 and 27 is expressed in state space as follows:

Second Scenario of First Experiment-When Link Capacity Is 4200 Packet/Seconds

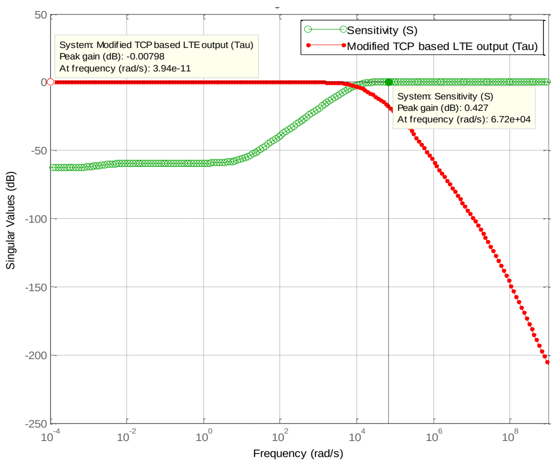

Figure 9: Singular Value Plot of the LTE Network When C=4200 Packet/Seconds.

The results in Figure 9 show that:

The modified TCP based LTE network model output recorded an error of 0.00798. This means that the modified system achieved an improvement in the network actual output responds with reduced error. The modified system recorded a sensitivity peak of 0.427dB. This means that the system can reject disturbances very well with reduced sensitivity.

The developed compensator Ck using mixed sensitivity synthesis for the second experiment with a link capacity of 4200 and weighting functions in Equations 26 and 27 is expressed in state space as follows:

Experiment II

This was carried out in two scenarios: when the link capacity is 3750 packet/seconds and 4200 packets/seconds using the weighting functions as expressed as follows:

$$W1 = \frac{1000(0.001s+10)}{s+10} \tag{28}$$

$$W2 = tf\left(\frac{1}{0.01}\right) \tag{29}$$

The first scenario of experiment I was carried out using TCP based LTE network link capacity =3750 packets/seconds:

First Scenario of Experiment II - When C=3750 Packet/Seconds

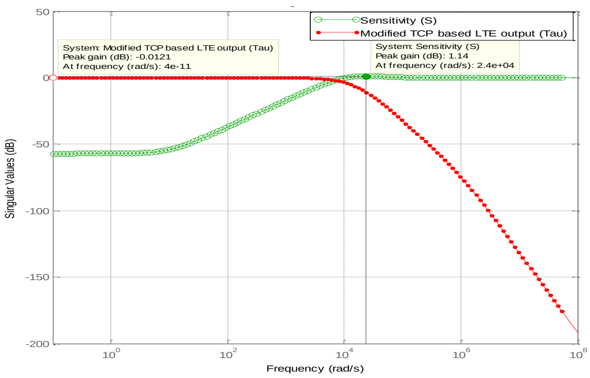

Figure 10: Singular Value Plot of the LTE Network When C=3750 Packet/Seconds

The results in Figure 10 shows that:

The modified TCP based LTE network model output recorded an error of 0.0121dB. This means that the modified system achieved an improvement in the network actual output responds with reduced error. The modified system recorded a sensitivity peak of 1.14dB. This means that the system can reject disturbances very well with reduced sensitivity.

The developed compensator Ck using mixed sensitivity synthesis for the first experiment with a link capacity of 3750 and weighting functions in Equations 28 and 29 is expressed in state space as follows:

Second Scenario of Experiment II - When C=4200 Packet/Seconds

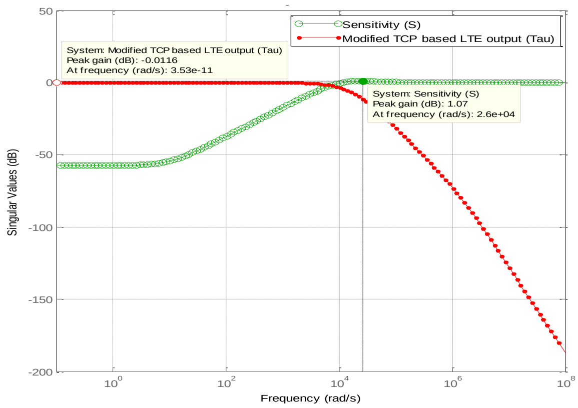

Figure 11: Singular Value Plot of the LTE Network When C=4200 Packet/Seconds

The results in Figure 11 shows that:

The modified TCP based LTE network model output recorded an error of 0.0116dB. This means that the modified system achieved an improvement in the network actual output responds with reduced error. The modified system recorded a sensitivity peak of 1.07dB. This means that the system can reject disturbances very well with reduced sensitivity.

The developed compensator Ck using mixed sensitivity synthesis for the second experiment with a link capacity of 4200 packets/seconds and weighting functions in Equations 28 and 29 is expressed in state space as follows:

CONCLUSIONS

The LTE network improvement was achieved using the mixed sensitivity synthesis method.

This work recommends that: TCP based LTE network performance improvement using mixed sensitivity synthesis should be applied in the current LTE networks in order to help enhance the data packet transfer. The mixed sensitivity synthesis offers a better error tracking capability and should be applied in the existing LTE and non-LTE networks since the mixed sensitivity synthesis achieves a good error level. Reduced data transfer error was achieved using mixed sensitivity synthesis that will enhance the LTE network performance. The LTE network performance was achieved using mixed sensitivity synthesis with better ability of traffic congestion cancellation, reduced data transfer error and better disturbance rejection ability.

REFERENCES

1. *Abdullah S. M., Younes O., Mousa H. M. and Abdul-kader H., (2016). Enhancing Performance of TCP Variants in LTE, International Journal of Computer Applications, Vol. 152, No. 1, pp. 41-47.*
2. *Abed, G.A., Ismail, M. and Jumari, K., (2011a), Modeling and Performance Evaluation of LTE Networks with Different TCP Variants, World Academy of Science, Engineering and Technology International Journal of Electronics and Communication Engineering Vol. 5, No. 3, pp. 443-448*
3. *Jamshaida K., Shihadaa B., Showaila A. and Levis P., (2014). Deflating Link Buffersin a Wireless Mesh Network, Journal Ad Hoc Networks, Elsevier, pp. 266-280*
4. *Testouri S., Saadaoui K. and Benrejeb M. (2012). Analytical Design of First Order Controllers for the TCP/AQM Systems with*

Time Delay, International Journal of Information Technology, Control and Automation (IJITCA) Vol.2, No.3.

5. *Hollot C. V., Misra V., Towsley D. and Gong W., (2002). Analysis and Design of Controllers for AQM Routers Supporting TCP Flows, IEEE Transactions on Automatic Control, Vol. 47, No. 6, pp. 945-959.*
6. *Mathwork, (2021), Mixed-Sensitivity Loop Shaping, Retrieved from:*
7. *Mareev N, Kachan D, Karpov K, Syzov D., (2018). Efficiency of a PID-based Congestion Control for High-speed IP-networks, Proc. of the 6th International Conference on Applied Innovations in IT, (ICAIIT), pp. 129-133*
8. *Bisoy S. K, Pattnaik P. K. (2017). Design of feedback controller for TCP/AQM networks, Engineering Science and Technology, an International Journal, Elsevier, Vol. 20, pp. 116-132.*
9. *Dukkipati RV. (2006), Analysis of design of control system using MATLAB, New Age International (P) Limited Publishers, New Delhi.*
10. *Agbaraji E.C., (2015), Robustness Analysis of a Closed-loop Controller for a Robot Manipulator in Real Environments, Physical Science International Journal, 8(3): 1-11.*
11. *Siemens E., Einhorn R., Aust A. & Fuerst L, (2010), Multi-Gigabit Challenges: Similarities between Scientific Environments and Media Production, Proc. of: The IASTED International Conference on Automation, Control, and Information Technology (ACIT-ICT 2010), Novosibirsk, Russia.*
12. *Pour H.M., Ashtiani H., Nikpour M., (2010), Active Queue Management in TCP Networks Based on fuzzy-PID Controller, Global Journal of Computer Science and Technology, Vol. 10 Issue 9 Ver.1.0, pp. 42-46.*
13. *Alvarez T., (2012). Design of PID Controllers for TCP/AQM Wireless Networks, Proceedings of the World Congress on Engineering, Uk, Vol. 2.*
14. *Agbaraji E.C., (2015), Robustness Analysis of a Closed-loop Controller for a Robot Manipulator in Real Environments, Physical Science International Journal, 8(3): 1-11.*
15. *Latha, K. Naveena, Pram Reddy, and DV Ravi Shankar. "Non Chemical Water Treatment Process For Tds Reduction In Cooling Tower–Specific Study On Electrical Conductivity And Turbidity." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8 (2018): 151-158.*
16. *Pachouri, V. I. P. I. N., and Anshul Sharma. "Active Vibration Suppression of Smart Plate Structure With Fractional-Order Pid Controller." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) Special Issue, Jun 2018, 41 48.*
17. *Hassaan, GALAL A. "On simple tuning of PID controllers for underdamped second order processes." International Journals of Mechanical and Production Engineering Research and development 4.3 (2014): 61-68.*
18. *Gnanaraj, F. Fredrick, and KR Vijaya Kumar. "Analysis of Vibration Detection using Active Controller in the Smart Cantilever Composite Beam with LQR and Fuzzy Techniques." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8. 5, Oct 2018, 67 76 (2018).*